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FINAL IAGS TECHNICAL TEAM MEMORANDUM 99-2
DEEP SOIL SAMPLING OF DEMOLITION AREA 1

FOR THE
CAMP EDWARDS IMPACT AREA
GROUNDWATER QUALITY STUDY

MASSACHUSETTS MILITARY RESERVATION
CAPE COD, MASSACHUSETTS

Prepared for

NATIONAL GUARD BUREAU
ARLINGTON, VIRGINIA

Prepared by

OGDEN ENVIRONMENTAL AND ENERGY SERVICES
239 Littleton Road, Suite 1B
Westford, Massachusetts 01886

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1. Introduction

1.1 Purpose of Investigation

Deep soil sampling of Demolition Area 1 ("Demo 1") was performed in accordance with the Workplan for Completion of Phase I Activities (Ogden, 1998b) for the Impact Area Groundwater Study (IAGS). The purpose of this sampling was to estimate the mass and approximate location of explosive compounds in soil. The results of this investigation will be used to evaluate alternatives for the removal of these chemicals to levels that are protective of drinking water.

1.2 Organization of Technical Memorandum

Section 2, Background, includes a discussion of the site location, prior investigations, and additional work being conducted or proposed for the area of interest. Section 3, Procedures, discusses the sampling and an analytical method used and Section 4, Results, includes the soil findings for the Demo1 area. Section 5, Evaluation, includes a discussion of contaminant distribution, contaminant fate-and-transport, and a preliminary risk evaluation. The remaining Sections include Section 6, Conclusions, Section 7, Recommendations, and Section 8, References.

2. Background

2.1 Location and Use

Demo 1 is located north of Forestdale Road and south of the Impact Area, near the current H Range at MMR. Demo 1 includes a natural 1-acre topographic depression, or kettle hole, that is approximately 45 feet below the surrounding grade. An access road surrounds the topographic low and circumscribes a 7.4-acre area (Figure 1). The bottom of the topographic low is a flat, cratered area (Photographs A and B). Low areas and individual craters remain wet for most of the winter and spring. Depth to groundwater from the base of the depression is about 40 feet. A concrete observation bunker was constructed on the north-facing slope of the south side of the topographic low, but has since been removed. Demolition activities appear to have been concentrated in the topographic low, based on historic maps and interview information. According to interview information, demolition activities in the topographic low did result in the intermittent ejection, or "kick out", of explosives and/or demolition materials from the depression into the surrounding area.

The following description of demolition activities appears in the Army Corps of Engineers' Archive Search Report (USACE, 1999).

> Demo 1 Range was established in its current location between 1986 and 1989 as a heavy demolition site (see plate 5) [note that Plate 5 of the USACE report shows current range locations, including Demo 1]. It is used primarily for the training of EOD and engineer units and for the destruction of various types of unexploded ordnance. Ordnance used at the Demo 1 Range includes explosive charges of C-4, TNT, and det-cord with a weight limit of 40 pounds, bangalore torpedoes, and claymore mines.

Use of the area prior to 1986 is also described in the Army Corps of Engineers' Archive Search Report (USACE, 1999).

> From 1970 to the mid 1970s, E-2 Range existed in the area of the current Demo 1 Range as a rifle squad in attack course (see plate 4). Available documentation does not describe the layout of the range, but does state that cal .30 and 7.62mm ammunition were used there.
>
> From the mid 1970s to the late 1980s, the range remained in the same location but was utilized as a heavy demolition range. Ordnance use during this time frame included C-4, TNT, and other explosive charges under 40 pounds. Since the late 1980s, no MMR range has been designated as the E-2 Range.

Table 1 depicts the type of munitions and the explosive mixtures and quantities for each. Table 1 indicates that the predominant explosive used in demolition munitions is hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) followed by 2,4,6-trinitrotoluene (TNT). Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazine (HMX) is not used in any of the demolition munitions. HMX is an impurity in the manufacturing process of RDX. It can be present with RDX at up to ten percent of the total RDX mass.

2.2 Prior Investigations

Demo 1 was sampled as part of Phase I of the IAGS with a total six surface soil grids and one boring completed as a monitoring well nest, MW-19. Samples were collected at the following locations:

- Boring 19 was installed in the middle of the flat cratered area at the bottom of Demo 1. The unsaturated zone was sampled at depths of 0-6 inches, 18-24 inches, 10-14 feet, 20-22 feet, 30-32 feet, and 42-44 feet below ground surface (bgs). The boring was completed as a monitoring well nest with a water table well (MW-19S) and a deep monitoring well (MW-19D).

Table 1. Explosive mixtures by munition type used at Demo 1.

Ordnance Type	Model	Explosive Filler	Explosive Quantity (g)	Other Information
Detonating Cord		PETN		
Blasting Fuse	M700	Black Powder		Potassium Nitrate = 74%, Sulfur = 11%, Charcoal = 15%
Electric Blasting Cap	M6	RDX		Intermediate charge of Lead Azide and igniter charge of Smokeless Powder
Non-Electric Blasting Cap	M7	RDX		Intermediate charge of Lead Azide and igniter charge of Lead Styphnate
Special Blasting Cap (Non-Electric)	J-1	RDX or PETN		Intermediate charge of Lead Azide and igniter charge of Lead Styphnate and Lead Azide
Special Blasting Cap (Non-Electric)	J-2	RDX or PETN		Intermediate charge of Lead Azide and igniter mixture
Demolition Charge	Block TNT	TNT	TNT = 226 or 453	
Demolition Charge	Block 112	C4	RDX = 516 Polyisobutylene = 51	
Demolition Charge	Block M5	C3	RDX = 854 Plastic Explosive = 249	(no composition information for plastic explosive)
Demolition Charge	Block M5A1	C4	RDX = 1032 Polyisobutylene = 92	
Demolition Charge	Block M3	C3 or C4	RDX = 929 Polyisobutylene = 92 or RDX = 796 Plastic Explosive = 224	(no composition information for plastic explosive)
Demolition Charge	Block M2	Tetrytol	TNT = 765 Tetryl = 255	
Dynamite	M1	RDX and Nitroglycerine		

Ordnance Type	Model	Explosive Filler	Explosive Quantity (g)	Other Information
EOD Demolition Charge	MK86 Mod 0	CH6	RDX = 32.2 Calcium Stearate = 0.5 Graphite = 0.15 Polyisobutylene = 0.15	
EOD Demolition Charge	MK87 Mod 0	CH6	RDX = 66.3 Calcium Stearate = 1.0 Graphite = 0.35 Polyisobutylene = 0.35	
EOD Demolition Charge	MK88 Mod 0	CH6	RDX = 97.5 Calcium Stearate = 1.5 Graphite = 0.5 Polyisobutylene = 0.5	
EOD Demolition Charge	MK89 Mod 0	A-3	RDX = 205, Wax = 20	
Shaped Charge (15 pounds)	M2A3, M2A4	Comp B	RDX = 2585 TNT = 1723	Includes 907 g booster of 50/50 Pentolite or 50 g A-3.TNT = 453, PETN = 453 or RDX = 46, Wax = 4
Shaped Charge (40 pounds)	M3, M3A1	Comp B	RDX = 7702 TNT = 5134	Includes 771 g booster of 50/50 Pentolite or 50 g A-3.TNT = 385, PETN = 385 or RDX = 46, Wax = 4
Bangolore Torpedo	M1A1	Amatol & TNT		Amatol = TNT & Ammonium Nitrate
Bangolore Torpedo	M1A2	Comp B & A-3		Comp B = RDX = 60%, TNT = 40% A-3 = RDX = 91%, Wax = 9%
Claymore Mine	M18, M18A1	C4	RDX = 619 Polyisobutylene = 61	

EOD – explosive ordnance disposal
PETN – pentaerythritol tetranitrate

- Grids 12A, 12B, 12C, 12D and 12E were located around the drill pad for boring 19. Each of the grids contained craters produced during demolition activities. Grid 12F was located outside the access road on the eastern end on Demo 1 in a moderately vegetated area, as a control grid for Demo 1. Each grid was sampled at depths of 0-6 inches and 18-24 inches bgs.

Results of these investigations are described in the Draft Completion of Work Report (Ogden, 1998a). Additional groundwater investigations were conducted in accordance with an Immediate Response Plan. Wells were installed at MW-31 located approximately 550 feet downgradient from MW-19; and at MW-32 and –33 located approximately 3500 feet downgradient from MW-19. Results of these investigations are described in the Workplan for Completion of Phase I Activities (Ogden, 1998b).

2.3 Current/Future Investigations

The Workplan for Completion of Phase I Activities (Ogden, 1998b) also specified additional groundwater sampling downgradient from Demo 1. Three additional monitoring wells (MW-34, MW-35, and MW-36) have been installed between MW-31 and MW-32/33 to locate the downgradient extent of groundwater contamination. The results of this groundwater investigation, and proposed future investigations, are provided in the Revised Response Plan for Demo Area 1 (Ogden, 1999a). Additional monitoring wells were installed between October 1999 and January 2000 cross-gradient to the groundwater flow direction between MW-31 and MW-34 (Figure 2). These wells are located downgradient of Demo 1 and are intended to help determine the width of the groundwater contamination. A background monitoring well was also installed upgradient of Demo 1. Results from installation and sampling of these wells will be provided in a future Technical Memorandum.

An additional 14 surface soil grids were proposed for Demo 1 (Ogden, 1999a), and were sampled in December 1999. These grids extend radially out from the Demo 1 area and are intended to assess the extent to which explosive contaminants may have been distributed beyond the kettle hole. The Guard will also conduct a reconnaissance of 100 percent of the ground surface within the perimeter road and 50 feet outside of it, to check for evidence of C-4 or other bulk explosives. There are historical reports of bulk explosives scattered in this area as a result of demolition training. If any bulk explosives are located in this area, they will be marked and removed to a safe holding area in accordance with unexploded ordnance (UXO) management procedures. These locations will have soil samples collected at a boring at the former location of the bulk explosives at depths of 0-3, 3-6, and 6-12 inches. Deeper sampling at these locations will be discussed with the regulatory agencies based on the results of the proposed samples. A limited reconnaissance on June 15, 1999 found evidence of C-4 along the base of the

kettle hole (Photograph C). Results from sampling at the grids and at the bulk explosive locations will be provided in a future Technical Memorandum.

3. Procedures

Sampling was performed in accordance with the Workplan for Completion of Phase I Activities (Ogden, 1998b). Soil borings were extended using a hollow-stem auger drill rig. Lanes for drill rig access were intrusively cleared of all magnetic anomalies to a depth of two feet. The nine borings were each advanced using a down-hole magnetometer for UXO clearance to a depth of 12 feet. Soil samples were collected for explosives on 1-foot intervals from 3 to 16 ft bgs at 9 locations. Based on the results from these samples, four of these borings (B-3, B-4, B-6, and B-9) were sampled on 2 ft intervals from 16 ft to the water table, approximately 44 ft. Samples were analyzed for explosive compounds using EPA Method 8330.

4. Results

RDX, HMX, nitroglycerin, and several TNT breakdown products (2A-DNT, and 4A-DNT 2,4-DNT) were detected in samples from six of the nine borings (B-1, -2, -3, -4, -5, and –6). The validated results are summarized in Table 2. Detections from the deep soil sampling and from the Phase I surface soil sampling are depicted in Figure 3.

Table 2. Validated deep soil borings results for Demo 1.

Sample ID	Boring	Start Depth (ft bgs)	End Depth (ft bgs)	Analyte	Result (ug/kg)	Flags
ABB001AAA	B-1	3	4	RDX	190	
ABB001AAA	B-1	3	4	HMX	150	
ABB001BAA	B-1	4	5		ND	
ABB001CAA	B-1	5	6		ND	
ABB001DAA	B-1	6	7		ND	
ABB001EAA	B-1	7	8	RDX	170	
ABB001EAA	B-1	7	8	HMX	170	J
ABB001FAA	B-1	8	9		ND	
ABB001GAA	B-1	9	10		ND	
ABB001HAA	B-1	10	11		ND	
ABB001IAA	B-1	11	12		ND	
ABB001JAA	B-1	12	13	RDX	1700	
ABB001KAA	B-1	13	14		ND	
ABB001MAA	B-1	15	16		ND	
ABB002AAA	B-2	3	4		ND	
ABB002BAA	B-2	4	5		ND	

Sample ID	Boring	Start Depth (ft bgs)	End Depth (ft bgs)	Analyte	Result (ug/kg)	Flags
ABB002CAA	B-2	5	6	2A-DNT	130	
ABB002CAD	B-2	5	6		ND	
ABB002DAA	B-2	6	7		ND	
ABB002EAA	B-2	7	8		ND	
ABB002FAA	B-2	8	9		ND	
ABB002FAD	B-2	8	9		ND	
ABB002GAA	B-2	9	10		ND	
ABB002HAA	B-2	10	11		ND	
ABB002IAA	B-2	11	12		ND	
ABB002JAA	B-2	12	13		ND	
ABB002KAA	B-2	13	14		ND	
ABB002LAA	B-2	14	15		ND	
ABB002MAA	B-2	15	16		ND	
ABB003AAA	B-3	3	4	RDX	230	
ABB003BAA	B-3	4	5		ND	
ABB003CAA	B-3	5	6		ND	
ABB003DAA	B-3	6	7		ND	
ABB003DAD	B-3	6	7		ND	
ABB003EAA	B-3	7	8		ND	
ABB003FAA	B-3	8	9		ND	
ABB003GAA	B-3	9	10		ND	
ABB003HAA	B-3	10	11		ND	
ABB003IAA	B-3	11	12	RDX	260	
ABB003IAA	B-3	11	12	HMX	210	
ABB003JAA	B-3	12	13		ND	
ABB003KAA	B-3	13	14		ND	
ABB003LAA	B-3	14	15		ND	
ABB003MAA	B-3	15	16		ND	
ABB003NAA	B-3	16	18		ND	
ABB003OAA	B-3	16	20		ND	
ABB003PAA	B-3	20	22		ND	
ABB003PAD	B-3	20	22		ND	
ABB003QAA	B-3	22	24		ND	
ABB003RAA	B-3	24	26		ND	
ABB003SAA	B-3	26	28		ND	
ABB003TAA	B-3	28	30		ND	
ABB003UAA	B-3	30	32		ND	
ABB003VAA	B-3	32	34		ND	
ABB003WAA	B-3	34	36		ND	
ABB003WAD	B-3	34	36		ND	
ABB003XAA	B-3	36	38		ND	

Sample ID	Boring	Start Depth (ft bgs)	End Depth (ft bgs)	Analyte	Result (ug/kg)	Flags
ABB003YAA	B-3	38	40		ND	
ABB003ZAA	B-3	40	42		ND	
ABB003ABA	B-3	42	44		ND	
ABB004AAA	B-4	3	4		ND	
ABB004BAA	B-4	4	5		ND	
ABB004CAA	B-4	5	6		ND	
ABB004DAA	B-4	6	7		ND	
ABB004EAA	B-4	7	8		ND	
ABB004FAA	B-4	8	9		ND	
ABB004GAA	B-4	9	10		ND	
ABB004HAA	B-4	10	11		ND	
ABB004HAD	B-4	10	11		ND	
ABB004KAA	B-4	13	14		ND	
ABB004LAA	B-4	14	15		ND	
ABB004MAA	B-4	15	16	2A-DNT	140	
ABB004NAA	B-4	16	18		ND	
ABB004OAA	B-4	18	20		ND	
ABB004PAA	B-4	20	22		ND	
ABB004QAA	B-4	22	24		ND	
ABB004RAA	B-4	24	26		ND	
ABB004SAA	B-4	26	28		ND	
ABB004TAA	B-4	28	30		ND	
ABB004TAD	B-4	28	30		ND	
ABB004UAA	B-4	30	32		ND	
ABB004VAA	B-4	32	34		ND	
ABB004WAA	B-4	34	36		ND	
ABB004XAA	B-4	36	38		ND	
ABB004YAA	B-4	38	40		ND	
ABB004ZAA	B-4	40	42		ND	
ABB005AAA	B-5	3	4		ND	
ABB005BAA	B-5	4	5		ND	
ABB005BAD	B-5	4	5		ND	
ABB005CAA	B-5	5	6	RDX	160	J
ABB005DAA	B-5	6	7		ND	
ABB005EAA	B-5	7	8		ND	
ABB005FAA	B-5	8	9		ND	
ABB005GAA	B-5	9	10		ND	
ABB005HAA	B-5	10	11		ND	
ABB005HAD	B-5	10	11		ND	
ABB005IAA	B-5	11	12		ND	

Sample ID	Boring	Start Depth (ft bgs)	End Depth (ft bgs)	Analyte	Result (ug/kg)	Flags
ABB005KAA	B-5	13	14		ND	
ABB005LAA	B-5	14	15		ND	
ABB005MAA	B-5	15	16		ND	
ABB006AAA	B-6	3	4	RDX	9300	
ABB006AAA	B-6	3	4	HMX	880	
ABB006BAA	B-6	4	5	HMX	150	J
ABB006BAD	B-6	4	5	2A-DNT	360	
ABB006BAD	B-6	4	5	4A-DNT	340	
ABB006BAD	B-6	4	5	RDX	220	J
ABB006BAD	B-6	4	5	HMX	200	J
ABB006CAA	B-6	5	6	RDX	1200	
ABB006DAA	B-6	6	7		ND	
ABB006EAA	B-6	7	8	2,4-DNT	150	
ABB006EAA	B-6	7	8	RDX	250	J
ABB006EAA	B-6	7	8	NG	4500	J
ABB006FAA	B-6	8	9		ND	
ABB006GAA	B-6	9	10	RDX	450	
ABB006HAA	B-6	10	11		ND	
ABB006HAD	B-6	10	11		ND	
ABB006IAA	B-6	11	12		ND	
ABB006JAA	B-6	12	13		ND	
ABB006KAA	B-6	13	14		ND	
ABB006LAA	B-6	14	15		ND	
ABB006MAA	B-6	15	16	RDX	380	
ABB006NAA	B-6	16	18	RDX	160	J
ABB006OAA	B-6	16	20		ND	
ABB006PAA	B-6	20	22		ND	
ABB006QAA	B-6	22	24	RDX	3400	
ABB006RAA	B-6	24	26	RDX	1200	
ABB006SAA	B-6	26	28		ND	
ABB006UAA	B-6	30	32	RDX	620	
ABB006VAA	B-6	32	34	RDX	280	J
ABB006WAA	B-6	34	36	RDX	150	J
ABB006XAA	B-6	36	38		ND	
ABB006XAD	B-6	36	38		ND	
ABB006YAA	B-6	38	40		ND	
ABB006ZAA	B-6	40	42		ND	
ABB006ABA	B-6	42	44		ND	
ABB007AAA	B-7	3	4		ND	
ABB007BAA	B-7	4	5		ND	

Sample ID	Boring	Start Depth (ft bgs)	End Depth (ft bgs)	Analyte	Result (ug/kg)	Flags
ABB007CAA	B-7	5	6		ND	
ABB007DAA	B-7	6	7		ND	
ABB007EAA	B-7	7	8		ND	
ABB007FAA	B-7	8	9		ND	
ABB007GAA	B-7	9	10		ND	
ABB007HAA	B-7	10	11		ND	
ABB007HAD	B-7	10	11		ND	
ABB007IAA	B-7	11	12		ND	
ABB007JAA	B-7	12	13		ND	
ABB007KAA	B-7	13	14		ND	
ABB007LAA	B-7	14	15		ND	
ABB007MAA	B-7	15	16		ND	
ABB008AAA	B-8	3	4		ND	
ABB008BAA	B-8	4	5		ND	
ABB008CAA	B-8	5	6		ND	
ABB008DAA	B-8	6	7		ND	
ABB008EAA	B-8	7	8		ND	
ABB008FAA	B-8	8	9		ND	
ABB008GAA	B-8	9	10		ND	
ABB008HAA	B-8	10	11		ND	
ABB008HAD	B-8	10	11		ND	
ABB008JAA	B-8	13	14		ND	
ABB008LAA	B-8	14	15		ND	
ABB008MAA	B-8	15	16		ND	
ABB009CAA	B-9	5	6		ND	
ABB009DAA	B-9	6	7		ND	
ABB009EAA	B-9	7	8		ND	
ABB009FAA	B-9	8	9		ND	
ABB009FAD	B-9	8	9		ND	
ABB009GAA	B-9	9	10		ND	
ABB009HAA	B-9	10	11		ND	
ABB009IAA	B-9	11	12		ND	
ABB009JAA	B-9	12	13		ND	
ABB009KAA	B-9	13	14		ND	
ABB009LAA	B-9	14	15		ND	
ABB009MAA	B-9	15	16		ND	
ABB009NAA	B-9	16	18		ND	
ABB009OAA	B-9	18	20		ND	
ABB009OAD	B-9	18	20		ND	
ABB009PAA	B-9	20	22		ND	

Sample ID	Boring	Start Depth (ft bgs)	End Depth (ft bgs)	Analyte	Result (ug/kg)	Flags
ABB009QAA	B-9	22	24		ND	
ABB009RAA	B-9	24	26		ND	
ABB009SAA	B-9	26	28		ND	
ABB009TAA	B-9	28	30		ND	
ABB009UAA	B-9	30	32		ND	
ABB009VAA	B-9	32	34		ND	
ABB009WAA	B-9	34	36		ND	
ABB009XAA	B-9	36	38		ND	
ABB009XAD	B-9	36	38		ND	
ABB009YAA	B-9	38	40		ND	
ABB009ZAA	B-9	40	42		ND	
ABB009ABA	B-9	42	44		ND	
ABB009BBA	B-9	44	46		ND	
ABB009CBA	B-9	46	48		ND	
ABB009DBA	B-9	48	50		ND	

ND – not detected
NG – nitroglycerine

5. Evaluation

5.1 Contaminant Distribution

The deep soil sampling results indicate sporadic detections of explosives, primarily RDX, at depths generally less than 16 feet bgs (Figure 3). This is consistent with known use of the site; the predominant explosive used for demolition activity was RDX, see Section 2. RDX was detected in four of the six borings that had detections. The other two borings (B-2 and –4) each had one detection of 2A-DNT, a TNT breakdown product. Only one of the four borings that were extended below 16 feet bgs had explosive compounds detected, and RDX was the only compound detected.

The highest RDX concentration, 9300 ug/kg, was observed in boring B-6 at a depth of 3 to 4 ft bgs. The highest HMX concentration, 800 ug/kg, was observed in the same boring at the same depth. Boring B-6 had the most frequent and deepest RDX detections, extending almost to the water table at 36 feet bgs. Figure 4 shows the distribution of RDX at sample location B-6 from 3 ft down to 44 ft.

Although boring B-6 had both the highest concentration and deepest detections of RDX, it does not appear that the latter are directly related to the former. The results for the soil intervals directly below the interval with the highest RDX concentration do not show a clear pattern suggestive of RDX migration. Concentrations in these intervals range from non-detect directly below the maximum (one of two samples from 4-5 ft bgs), to 1200

ug/kg in the following interval (5-6 ft bgs), to non-detect in the following interval (6-7 ft bgs). Nine of the 13 intervals sampled below 16 feet had no detectable concentrations of explosives. If RDX had leached to the water table at this location, one might expect more consistent levels of explosive detected in the lower intervals. However, it is possible that the sporadic RDX detects are reflective of preferential flow within the unsaturated zone.

5.2 Contaminant Fate-and-Transport

The conceptual model for the site was described in Ogden, 1998a and ETA, 1997. RDX and the other explosives reside on the soil surface as particulates. Redistribution of the soil to fill in craters may have resulted in surface soil containing particulate explosive mixed to a depth of approximately 8 feet. The major fate mechanism for RDX in soil is dispersion, advection, and diffusion unless anaerobic conditions exist which then can result in biodegradation and abiotic transformations playing an important role. The redox state of soil at Demo 1 has not been determined. The major explosives contaminants, TNT and RDX, have aqueous solubilities of 100 and 42 mg/L, respectively, and from a kinetic point of view, dissolve slowly into aqueous solution. Because of these factors, high concentrations of these compounds can persist in near-surface soils for decades. For example Haywood et al. (1995) found solid chunks of RDX and HMX visible on the soil surface at an explosives test facility at Los Alamos, NM which was used for one year and abandoned in the mid 1950's. RDX once in solution is mobile in the soil and will result in the migration of RDX into groundwater.

The lithologic data for Demo 1 suggest increased clay content near the ground surface, which may contribute to ponding of surface runoff and dissolution of contaminants. The drilling logs for these borings indicate clay and sand is present in the top 7to 10 ft, which then changes to mostly sand below 10 ft. This is consistent with the visual observation of ponding of water in the Demo 1 area during the wetter winter months.

On the other hand, the presence of clay near the ground surface may contribute to retention of RDX in this soil. Sorption of RDX is primarily dependent upon CEC, pH, clay content, organic carbon, and extractable iron (Ainsworth et al. 1993). The inorganic components of clay soil, e.x. iron and cations are more important than organic matter content in predicting sorption (Myers et al. 1998; Haderlein et al. 1996; Leggett 1991; Pennington, 1988; and Leggett, 1985). Ainsworth et al. (1993) and Tucker et al. (1985) found a poor correlation between partitioning coefficient (K_d) and fraction of organic carbon (f_{oc}). The increased clay content near the ground surface at Demo 1 may contribute to retention of RDX onto soil near the surface.

The results of the limited number of deep soil borings suggests one of the following scenarios for contaminant fate and transport:

- A continuing source of groundwater contamination exists at Demo 1 that was not encountered by the borings advanced in this investigation. The results for the 22-24 ft bgs and 30-36 ft bgs intervals in boring B-6 suggest that lateral migration of contaminants may have occurred from a nearby source. Such a scenario would explain the sudden increases in RDX concentration in intervals after non-detectable levels in preceding samples. Lateral migration of leachate is possible along minor discontinuities in soil types, due to changes in soil permeability.
- A continuing source of groundwater contamination exists at Demo 1 and includes the area sampled in this investigation. However, the contaminant mass is distributed heterogeneously such that existing samples did not include this material. Contaminant concentrations in soil pore water are too low to be detectable in deep soil samples.
- There is no continuing source of groundwater contamination at Demo 1. Therefore, contaminant levels at Demo 1 should gradually decrease in groundwater as the contamination is flushed out of the aquifer. Of three scenarios presented this is the least likely since it does not appear to be supported by the limited groundwater sampling at MW-19S, which does not show a decrease in explosive levels.
- A continuing source of groundwater contamination exists at Demo 1 and includes the area sampled in this investigation. The relatively low contaminant levels detected throughout Demo 1 are the source contributing contaminants to the groundwater.

Each of these scenarios is consistent with the conceptual model summarized above.

5.3 Preliminary Risk Evaluation

Currently, there are no risk-based criteria for soils containing explosive compounds. Such criteria are typically calculated on a site-specific basis considering the opportunity for direct exposure of humans to the soils, and the opportunity for indirect exposure through leaching to groundwater. Such calculations would require use of a groundwater model and/or experimental determination of the soil concentration that would pose a threat to groundwater.

Cleanup standards used at other sites for soil remediation are summarized in Table 3. These standards were developed after conducting fate-and-transport modeling coupled with a risk analysis. In comparison, the maximum explosive levels seen at Demo 1 are within the ranges of or below the remediation goals established for these other sites with explosives. However, cleanup standards utilized at sites where groundwater protection is not a key factor may be higher than cleanup levels that will be determined protective of the Sole Source aquifer beneath MMR.

Table 3. Explosive Cleanup Standards for Other Sites

Location	Explosive Compound	Remediation Goal (ug/kg)
DOE Pantex Site (LANL, 1999)	RDX	17,000
	HMX	34,000,000
	DNT	2,800
	TNT	64,000
Joliet AAP (Pennington et al, 1998)	TNT	190,000
Various AAPs (Craig et al, 1997)	RDX	1,000 to 52,000
	HMX	1,000 to 3,722,000
	2,4-DNT	420 to 5,000
	2,6-DNT	400 to 5,000
	TNT	1,000 to 33,000

The Massachusetts Contingency Plan (MCP) lists several criteria which may be considered for explosive compounds (Table 4). MCP Method 1 S-1/GW-1 cleanup standards are conservative standards that take into consideration direct contact and leaching to groundwater used as a drinking water source. Unfortunately, standards have only been developed for one compound on the Method 8330 target analyte list, 2,4-DNT. MCP S1 Reportable Concentrations (RCS1) establish the threshold concentrations above which notification to the MADEP of a release of hazardous materials is required. The RCS1 Reportable Concentrations are applicable for soil existing above a drinking water resource and take into account direct contact with impacted soil. These are not clean-up standards; however, they do establish an important regulatory threshold and they provide a frame of reference for compounds which may be detected during the soil sampling.

Table 4. Comparison of Demo 1 soil results with MCP criteria for explosives.

Explosive Compound	MCP RCS1 Soil Reportable Conc. (ug/kg)	MCP S-1/GW-1 Soil Standard (ug/kg)	Maximum Explosive Level At Demo 1 (ug/kg)
2A-DNT	-	-	800
4A-DNT	-	-	400
2,4-DNT	700	700	150
HMX	-	-	880
Nitroglycerine	50,000	-	4500
Picric Acid	100,000	-	160
RDX	100,000	-	9300

6. Conclusions

2A-DNT, 4A-DNT, 2,4-DNT, HMX, NG, and RDX are present in the soil at Demo 1. The presence of the detected explosives is consistent with known munitions used at the Demo 1 site. The distribution of contaminants in the unsaturated zone suggests that there is no high concentration source upon which remediation efforts could be focussed. Therefore, either the source has not been located yet, or the relatively low contaminant levels detected throughout Demo 1 are the source contributing contaminants to the groundwater.

7. Recommendations

It is recommended that unsaturated zone modeling be performed to determine what levels of explosives in soil will result in exceedance of the EPA Health Advisories (HAs). In order to perform this modeling, the dissolution rate of RDX should be quantified. This information will be useful in determining if the currently known levels of soil contamination are likely to be a significant source of groundwater contamination. The modeling would also allow calculation of a soil clean-up level which will prevent groundwater levels exceeding the HA, if remediation is deemed necessary for the soils at this site.

Another recommendation is to consider additional soil sample locations east of the current locations in Demo 1. The current locations appear to have characterized the center of the topographic depression. If there is a high concentration source of contaminants, it may be located in the eastern portion of the depression, surrounding or upgradient of MW-19. A network of nine additional soil borings is proposed in this area, with soil sampling at the same intervals as were used for the study described herein.

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Figure 1. Location of Demo 1 at MMR.

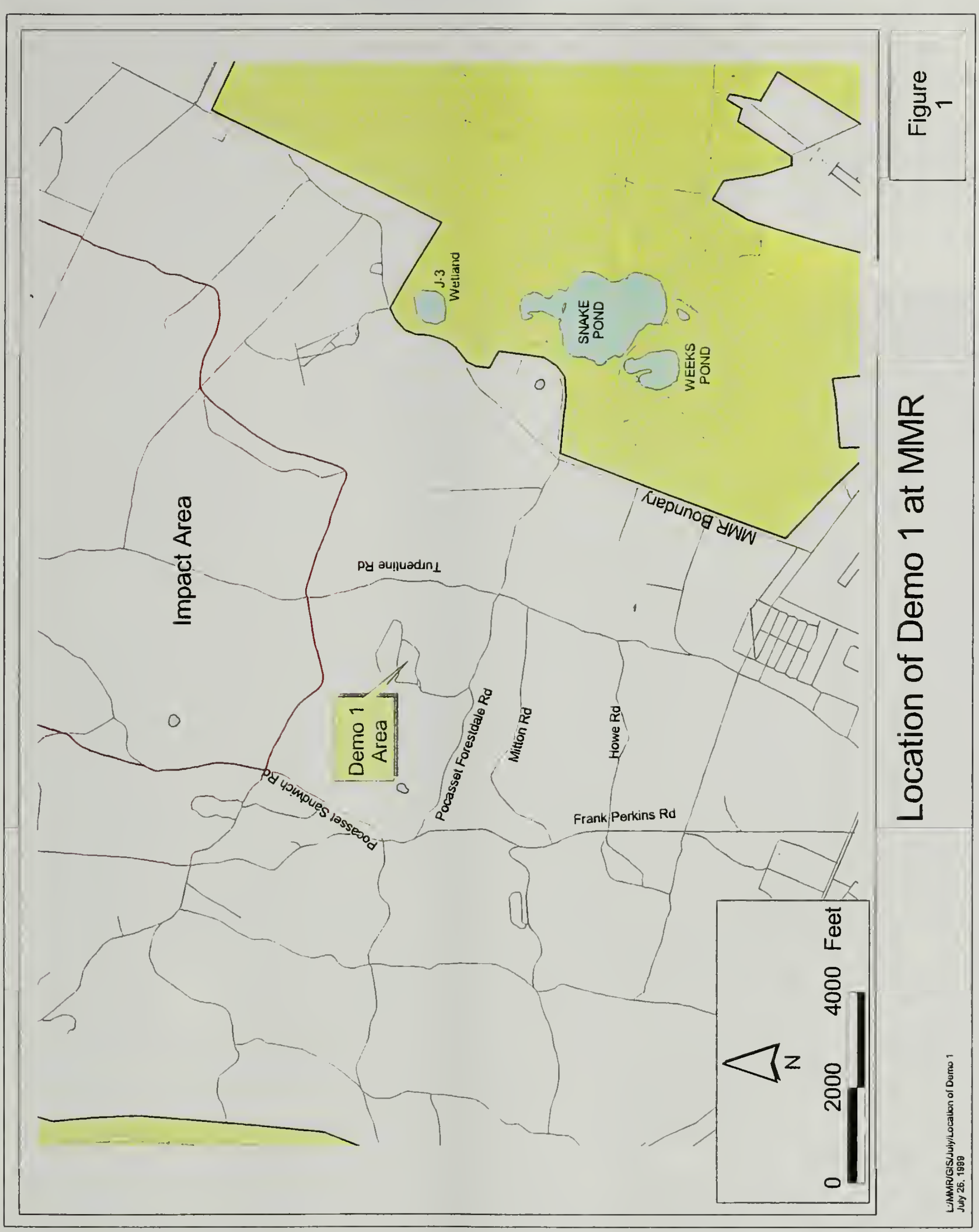
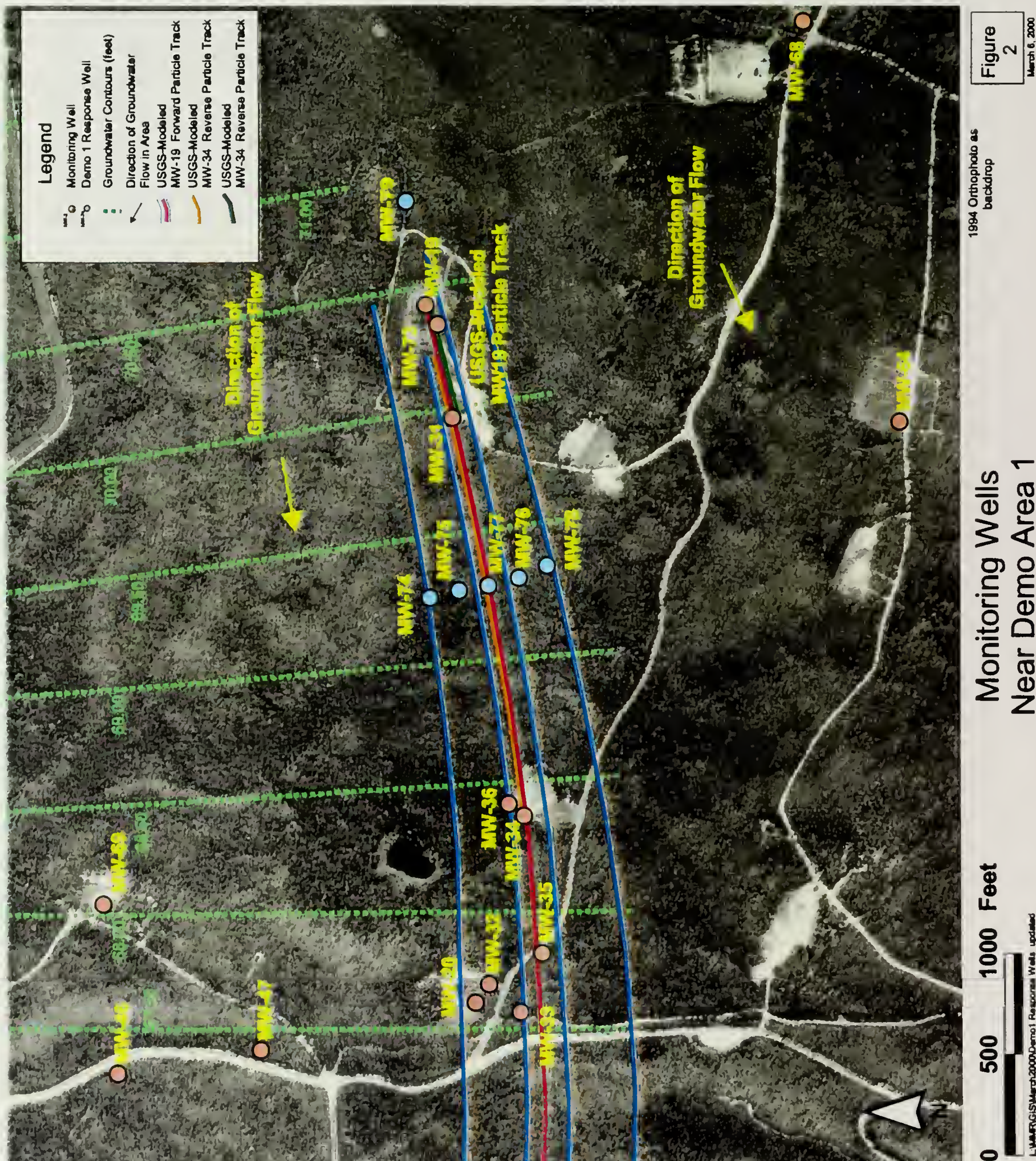
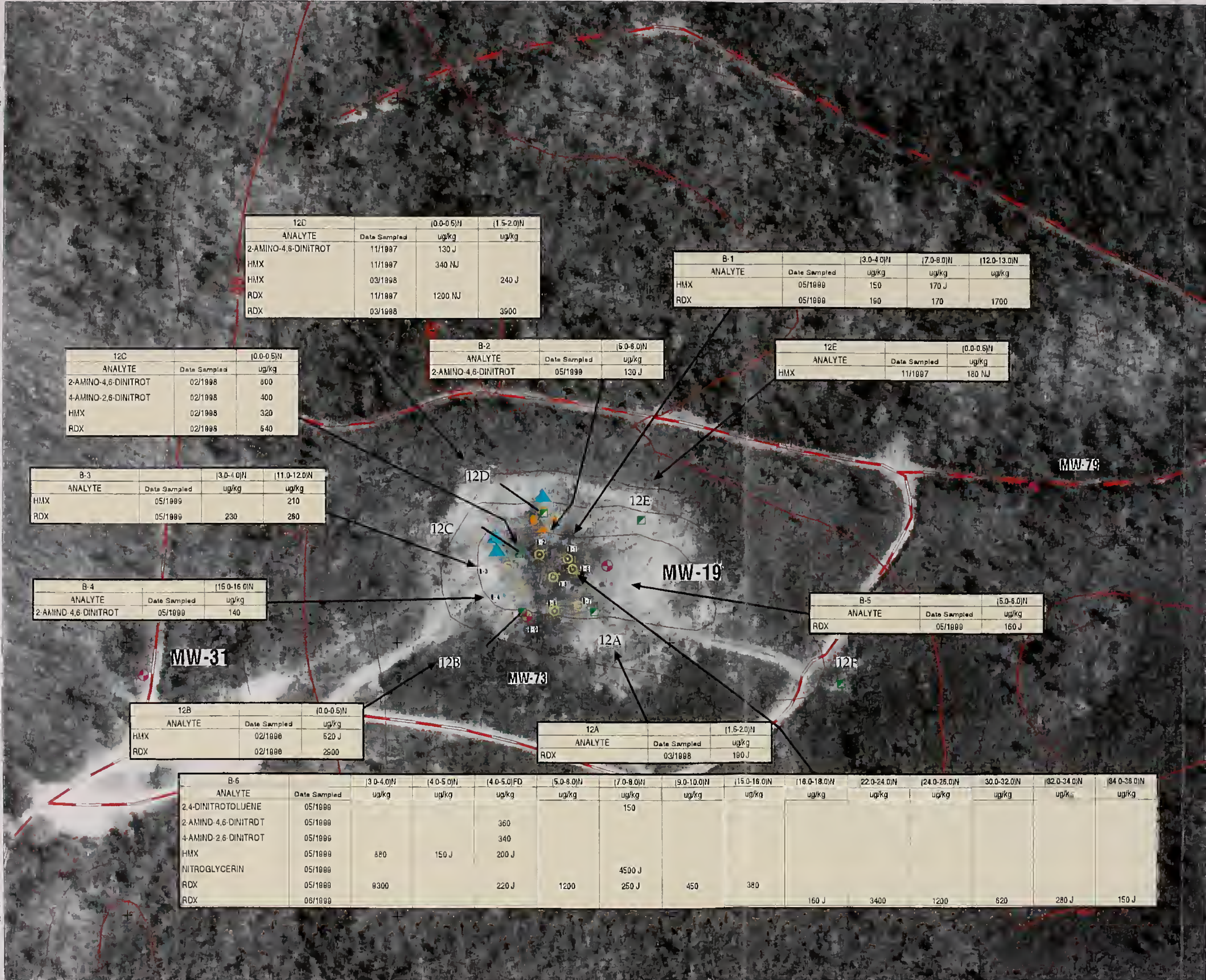


Figure 2. Monitoring wells near Demo 1 area.





12D ANALYTE	Date Sampled	(0.0-0.5)N ug/kg	(1.5-2.0)N ug/kg
2-AMINO-4,6-DINITROT	11/1997	130 J	
HMX	11/1997	340 NJ	
HMX	03/1998		240 J
RDX	11/1997	1200 NJ	
RDX	03/1998		3900

B-1 ANALYTE	Date Sampled	(3.0-4.0)N ug/kg	(7.0-8.0)N ug/kg	(12.0-13.0)N ug/kg
HMX	05/1999	150	170 J	
RDX	05/1999	160	170	1700

12C ANALYTE	Date Sampled	(0.0-0.5)N ug/kg
2-AMINO-4,6-DINITROT	02/1998	800
4-AMINO-2,6-DINITROT	02/1998	400
HMX	02/1998	320
RDX	02/1998	640

B-2 ANALYTE	Date Sampled	(5.0-6.0)N ug/kg
2-AMINO-4,6-DINITROT	05/1999	130 J

12E ANALYTE	Date Sampled	(0.0-0.5)N ug/kg
HMX	11/1997	180 NJ

B-3 ANALYTE	Date Sampled	(3.0-4.0)N ug/kg	(11.0-12.0)N ug/kg
HMX	05/1999		210
RDX	05/1999	230	260

B-4 ANALYTE	Date Sampled	(15.0-16.0)N ug/kg
2-AMIND-4,6-DINITROT	05/1999	140

B-5 ANALYTE	Date Sampled	(5.0-6.0)N ug/kg
RDX	05/1999	160 J

12B ANALYTE	Date Sampled	(0.0-0.5)N ug/kg
HMX	02/1998	520 J
RDX	02/1998	2900

12A ANALYTE	Date Sampled	(1.6-2.0)N ug/kg
RDX	03/1998	190 J

B-6 ANALYTE	Date Sampled	(3.0-4.0)N ug/kg	(4.0-5.0)N ug/kg	(4.0-5.0)FD ug/kg	(5.0-6.0)N ug/kg	(7.0-8.0)N ug/kg	(9.0-10.0)N ug/kg	(15.0-16.0)N ug/kg	(16.0-18.0)N ug/kg	(22.0-24.0)N ug/kg	(24.0-26.0)N ug/kg	(30.0-32.0)N ug/kg	(32.0-34.0)N ug/kg	(34.0-36.0)N ug/kg
2,4-DINITROTOLUENE	05/1999					150								
2-AMIND-4,6-DINITRDT	05/1999			360										
4-AMIND-2,6-DINITROT	05/1999			340										
HMX	05/1999	680	150 J	200 J										
NITROGLYCERIN	05/1999					4500 J								
RDX	05/1999	9300		220 J	1200	250 J	450	380						
RDX	06/1999								160 J	3400	1200	620	280 J	150 J

MMR Groundwater Study

LEGEND

- Groundwater Wells
- Soil Borings
- Soil Grid Samples

ug/kg	Micrograms Per Kilogram
NJ	Tentatively Identified, Estimated Quantity
J	Estimated Quantity
FD	Field Duplicate
N	Normal Environmental Sample

IMAGE DATE: 1994
All sample depth measurements are in feet

BASEMAP LEGEND

- Impact Area Boundary
- Water Bodies
- Roads
- Paths
- Power/Transmission Lines
- 3 Meter Contours
- C4 Residuals
- Smoke Grenade

LOCATION MAP

NOTES & SOURCES

Chemical database last queried on: Feb 22 20:05
Map coordinates: Stateplane, NAD83, Zone 4151, Meters

ORTHOPHOTOGRAPHY: 1:5000 digital black & white orthophotos
Source: MASSGIS; Resolution: 1/2 meter; Date Flown: 1994

TOPOGRAPHY: 3 meter contours generated from digital terrain models (DTMs)
Source: MASSGIS

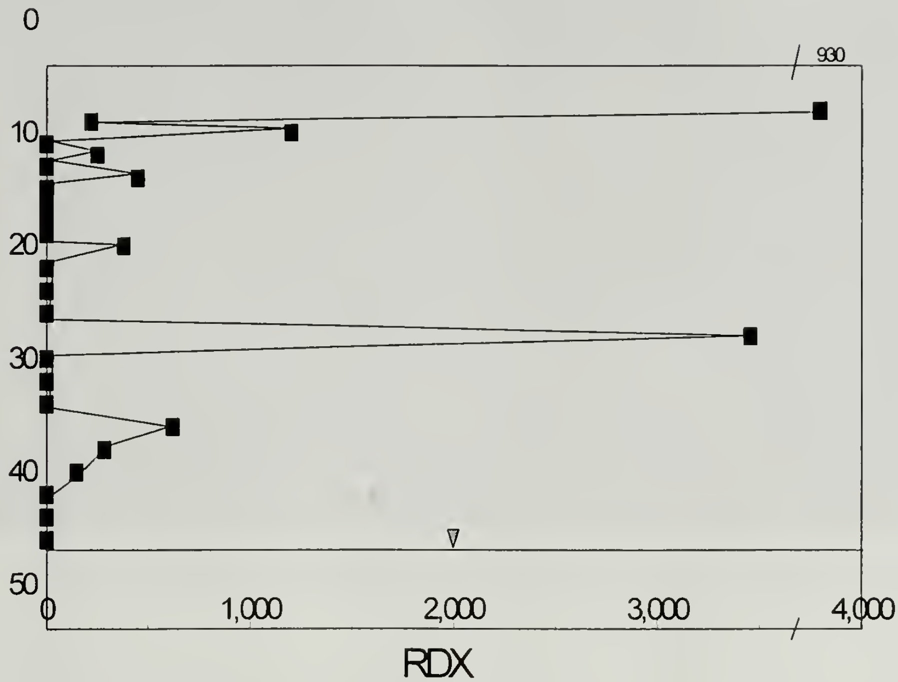
TITLE

CONCENTRATIONS OF EXPLOSIVES IN SOIL SAMPLES
Area 12

0 125 FEET
0 38 METERS

FIGURE 3

Figure 4. RDX Soil Profile Results for Boring B-6 at Demo 1.



Photograph A. Demo 1 area looking northwest from entrance on the east

Photograph B. Demo 1 area looking northeast with MW-19 in the foreground.

Photograph C. C-4 residual, grey material, located at Demo 1.

ATTACHMENT 1
RESPONSE TO EPA COMMENTS DATED 11/3/99

Specific Comments:

1. Page 1, Section 2.1 – Prior to 1986 (starting in the mid-1970's), Demo-1 was known has demolition range E-2. EPA comments on the Army Corps Archive Search Report (ASR) for MMR contain the known years of use under this designation.

   Text will be added discussing Demo 1 use prior to 1986.

2. Page 1, Section 2.1 – After the last sentence in the first paragraph of this section, please add the following: "According to interview information, demolition activities in the topographic low did result in the intermittent ejection, or "kick out", of explosives and/or demolition materials from the depression into the surrounding area."

   Text will be added.

3. Page 11, Section 5.1 – The first sentence should be restated. Sporadic detections of explosives were detected to a depth of 44 feet bgs (6 feet below the water table).

   The word "generally" was inserted to indicate that the majority of detections were less than 16 feet deep. The deeper detections at B-6 were described in the second paragraph.

4. Page 12, Section 5.2 – In the eighth line of the first paragraph, please rewrite the sentence to include more exact information. Other NGB reports refer to solubility of RDX as approximately 42 mg/l.

   The text will be revised.

5. Page 12, Section 5.2 – In the 4th Paragraph on page 12, should be changed to read as follows: "Based on the limited number of deep soil boring locations, the following are potential scenarios for contaminant fate and transport:"

   The text will be revised.

   A new fourth bullet should then be added, which states "A continuing source of groundwater contamination exists at Demo 1 and includes the area sampled in this investigation. The relatively low contaminant levels detected throughout Demo 1

are the source contributing contaminants to the groundwater."

The text will be revised.

6. <u>Page 13, Section 5.3</u> – Cleanup standards utilized at other sites (mostly Army Ammunition Plants with high levels of contamination) have little relevance to cleanup levels which will be determined protective of the Sole Source aquifer beneath MMR. Please add a sentence stating this.

   The text will be revised.

7. <u>Page 14, Section 7.0</u> – Based on the limited soil and groundwater data collected to date (sporadic low level detections of explosives in soils, combined with concentrations in groundwater which do not appear to be decreasing), it appears that the available chemical data (such as solubility, volatility, adsorption, decay behavior, etc.) for explosives (RDX in particular) may not be accurate for the particular environment (soil type, precipitation, etc.) at MMR. These site-specific fate and transport parameters must be determined for RDX, HMX, and TNT, among others. It would then need to be determined that modeling based upon these values reasonably approximates what is being observed in the field before cleanup levels can be established. It appears that Demo 1 soils are a continuing source area, and that given the damage to the aquifer, downgradient groundwater capture and treatment, in addition to source area remediation, may be required to insure that further RDX does not enter groundwater in the vicinity of the site.

   The Guard believes that it is not scientifically defensible to suggest that the limited data collected to date from Demo 1 are indicative of inaccurate fate-and-transport property data in the literature. The sporadic nature of the detections can be explained in several ways, as indicated in Section 5.2, which are consistent with the fate-and-transport properties in the peer-reviewed literature.

   The Guard agrees that a fate-and-transport model for Demo 1 would have to be developed that was consistent with existing conditions before cleanup levels could be established. The model parameters would include site-specific fate-and-transport property data. A proposal for modeling in the unsaturated zone was submitted to the regulatory agencies for review on July 22, 1999. The Guard looks forward to receiving comments on this proposal and moving forward with the modeling effort.

   EPA concurs with the recommendation for additional soil sampling grids east of MW-19, and these grids should be added during the next step in the investigation/remediation process.

The Guard proposes to conduct additional deep soil sampling in the area east of the existing borings. The purpose of these new borings would be to characterize the remainder of the unsaturated zone within the topographic depression, where there is the highest probability of a continuing source of contamination. The scope of this investigation would be identical to the previous deep soil sampling, but relocated to cover the eastern half of the topographic depression. A description of this proposal has been added to the text.